Formerly Utilized MED/AEC Sites Remedial Action Program

Radiological Survey of the Hooker Chemical Company Niagara Falls, New York

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Final Report

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by the Atomic Energy Commission (AEC) for determination of the condition of sites formerly utilized by the Manhattan Engineering District (MED) and the AEC for work involving the handling of radioactive materials. Since the early 1940's, the control of over 100 sites that were no longer required for nuclear programs has been returned to private industry or the public for unrestricted use. A search of MED and AEC records indicated that for some of these sites, documentation was insufficient to determine whether or not the decontamination work done at the time nuclear activities ceased is adequate by current guidelines.

These reports contain the results of surveys of the current radiological condition of these sites. Based upon the findings of the surveys, further evaluation will be made at those sites where radioactivity above natural background is identified to determine whether further measures should be undertaken to assure the protection of the public health and safety.

The work reported in this document was conducted by the following members of the Health and Safety Research Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee:

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Abstract

The results of a radiological survey of a portion of the Hooker Chemical Company, Niagara Falls, New York, are presented in this report. The survey was conducted over 5.5-acres in which uranium-bearing materials were handled in the early 1940's. The survey included direct measurements of alpha, beta-gamma, and external gamma radiation throughout the site, measurement of transferable alpha and beta contamination levels in the buildings, determination of uranium and radium concentrations in the soil on the site, measurement of radon and radon daughter concentrations in the buildings, and determination of radionuclide concentrations in surface water samples. The results of the survey indicate that radiation levels throughout the site are within pertinent guidelines for unrestricted release of the property.

Introduction

At the request of the Energy Research and Development Administration (ERDA), Oak Ridge Operations, a radiological survey was conducted in Niagara Falls, New York, at the Hooker Chemical Company. The Hooker Chemical Company is located in an industrial area on the north bank of the Niagara River approximately two miles east of the Niagara Falls. A map of the entire Hooker Chemical Company and the immediate vicinity is

materials included furnace liners and other solid waste materials thought to contain enough uranium to warrant uranium recovery. The materials were brought in by railroad, unloaded, processed, repackaged, and shipped out by rail. All uranium operations were confined to 5.5-acres adjacent to the New York Central Railroad (see Fig. 1). Five buildings, four of which still remain, were used in the uranium operations. The equipment used for the uranium operations was removed, and these buildings were outfitted for new processes. A railroad spur, which was rebuilt since the uranium operations, borders the east edge of the former uranium processing area.

The survey was undertaken to characterize the present radiological status of the property. It was conducted by five members of the Health and Safety Research Division of the Oak Ridge National Laboratory during the period of October 11-15, 1976. The survey consisted of the following measurements:

1. external gamma radiation levels outdoors at one meter above the surface on an approximate 50-ft grid in the area of uranium processing;

2. beta-gamma radiation levels at 1 cm above the surface on the same grid, including a portion of the area once covered by Building 5, which has been demolished;

3. alpha and beta contamination levels (fixed and transferable) on surfaces inside the four buildings remaining from the uranium operations;

and immediately off-site; and

7. "background" radionuclide content in soil and water samples obtained locally but remote from the plant site.

"Contamination", as used in the report, refers to radioactive materials deposited in or on surfaces whether fixed or transferable. Survey meter readings made on surfaces generally indicate the level of fixed contamination while standard smear techniques are used to determine the levels of transferable contamination.

Measurement of Alpha and Beta Contamination Levels

Direct readings of alpha contamination were made outdoors at points determined by the rectangular grid shown in Fig. 2, and throughout the buildings shown in Figs. 3-7. Measurements were taken with alpha scintillation survey meters which are described in Appendix I. Standard smear techniques were used to measure transferable alpha and beta contamination levels inside the building. The smear counters are described in Appendix I.

Measurement of Beta-Gamma Radiation Levels

Beta-gamma dose rates were measured at 1 cm above the surface outdoors at the grid points indicated in Fig. 8 and throughout the buildings. These measurements were made with Geiger-Muller survey meters which are described in Appendix I.

Measurement of Radon and Radon Daughter Concentrations in the Buildings

For the measurement of instantaneous radon concentrations in the air in buildings 6, 7, 8, and 9 in the "D" area, air samples were taken

known radon concentration indicated that the detection efficiency for the Lucas-chamber counting system is 2.02 pCi/l/cpm. The Lucas chamber and photomultiplier tube are described in Appendix II.

Air samples were also taken in the buildings for the measurement of radon daughters. Air was pumped for five minutes at approximately 12 liters per minute through a membrane filter with a maximum pore size of 0.4 μm. The filter was counted using an alpha spectrometry technique refined by Kerr.[1] This technique is described in Appendix II.

Measurements of External Gamma Radiation Levels

External gamma radiation levels were measured with NaI scintillation survey meters which are described in Appendix I. Readings were taken at one meter above the surface at the outdoor locations shown in Fig. 9 and at (roughly) uniformly spaced intervals inside the buildings. Scintillation survey meter measurements are indicative of the instantaneous exposure rates at the point of measurement.

Measurement of Uranium and Radium Concentrations in Soil

Soil samples were taken at 21 of the grid points shown in Fig. 10 (see Table 6). In addition, two background samples were taken in the vicinity of the Hooker Chemical Company at points removed from the area of uranium operations. The soil samples were packaged in plastic bags before being returned to Oak Ridge, where they were dried for 24 hours at 110°C and then pulverized to a particle size of -35 mesh (500 μm). Next, aliquots from each sample were transferred to plastic

Measurement of Radioactivity in Surface Water

A water sample was taken from the Niagara River at a point where process water from Hooker flows into the river (see Fig. 1). In addition, a tap-water sample was taken from the city water system. The samples were analyzed at ORNL for radium, thorium and uranium using sequential separation techniques. Sludge samples taken from man-holes 301 and 306 (Fig. 2) were analyzed at ORNL for uranium by neutron irradiation and subsequent counting of delayed neutrons from ^{235}U.

Survey Results

Direct and transferable alpha and beta-gamma contamination levels and external gamma radiation levels were measured throughout Buildings 6, 7, 8, and 9. In most areas, readings were at or near the background level. For convenience in reporting, only readings considered to be above the background level, plus typical readings from areas with little or no radioactive contamination, were recorded. In all indoor areas for which no readings are reported, alpha and beta-gamma contamination levels and external gamma radiation levels did not significantly exceed the lowest measurements reported in Tables 1-4.

Alpha and Beta Contamination Levels

Direct measurements of alpha contamination levels on indoor surfaces are reported in Tables 1-4 for locations shown in Figs. 3-7. Measurements were taken on floors, walls, elevated structural members, and ceilings. All direct alpha measurements for indoor surfaces were below

level was 170 dpm/100 cm^2. In guidelines ...

strictest limits* for average and maximum allowable surface contamination levels for alpha emitters are 100 dpm/100 cm^2 and 300 dpm/100 cm^2, respectively, by direct reading. (These limits apply to ^{226}Ra and ^{230}Th, among other nuclides.) The direct alpha reading at grid point B-2 was made over an area of 100 cm^2 and hence is below the maximum allowable limits.

Smear samples were taken throughout the buildings for the determination of transferable alpha and beta contamination levels. All smears showed less than 10 dpm/100 cm^2 of transferable alpha contamination; this is below the NRC(2) and proposed ANSI(3) limits for every nuclide. Those locations at which transferable beta contamination exceeded 100 dpm/100 cm^2 are listed in Table 5. Transferable beta radiation levels did not exceed 200 dpm/100 cm^2. This is also well within the NRC and proposed ANSI limits of 1000 dpm/100 cm^2 for transferable beta contamination.

Direct Measurement of Beta-Gamma Dose Rates

Direct measurements of beta-gamma dose rates taken at 1 cm above the surfaces inside the buildings are listed in Tables 1-4 for locations shown in Figs. 3-7. Measurements were taken on floors, walls, elevated

*Measurements may not be averaged over more than one square meter. The maximum contamination level applies to an area of not more than 100 cm^2.

Building 21). Readings were in the range of 0.02-0.07 mrad/hr, with the highest level being measured near the southeast corner of Building 6. According to the NRC guidelines(2) for unrestricted use, average beta-gamma dose rates below 0.2 mrad/hr by direct reading are acceptable.

Measurement of External Gamma Radiation

Measurements of external gamma radiation at 1 meter above the surface at the grid points are given in Fig. 9. Indoor measurements are reported in Tables 1-4 for locations shown in Figs. 3-7. Most measurements were below 12 μR/hr, which is within the range of background measurements which have been taken in the Niagara Falls area. The highest external gamma radiation levels found on the site were in the northwest corner of Building 9, where one reading of 28 μR/hr was recorded on the lower level of the building underneath a stairway. External gamma radiation levels were slightly elevated outdoors in the vicinity of Building 6. Measurements of 13 to 23 μR/hr were recorded at grid points within 100 feet of that building.

Results of Soil Sample Analyses

Concentrations of uranium and radium found in soil samples taken on-site are listed in Table 6; locations are shown in Fig. 10. The maximum concentration of ^{238}U found in on-site samples was 2.1 $\pm$ 0.1 pCi/g; this is not significantly different from the average ^{238}U concentration of 1.3 $\pm$ 0.7 pCi/g found in background samples OSB-1 and OSB-2

samples. The results for the 21 on-site samples indicate that uranium and radium are in approximate equilibrium in the soils on the site.

Radon and Radon Daughter Measurements in the Buildings

In Buildings 6, 7, 8, and 9, air samples were taken for the measurement of instantaneous radon concentrations. Measurements were in the range of <0.1-1.1 pCi/ℓ (see Table 7) with the highest concentration being recorded in Building 6. Additional air samples were taken for the measurement of radon daughter concentrations in the buildings (see Table 8). Samples from Buildings 6, 7, and 9 showed radon daughter concentrations below 0.001 WL,* and the sample from Building 8 showed a concentration of 0.003 WL. It should be noted that these measurements were taken over a short period of time; radon and radon daughter levels in a building may vary significantly over a period of several months. However, the results concerning radon and radon daughters in the buildings are consistent with the fact that little radium was found in the soils on the site.

The dose to individuals delivered by radon is small compared with the dose delivered by its daughter products (about 500 times less at equilibrium[4]). However, the measurement of radon concentrations in the buildings allows one to estimate the potential radon daughter levels,

*A working level (WL) is defined as any combination of radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy.

concentration in the air in Building 8 might be as high as 0.007 WL

(= $\frac{0.0085 \text{ WL}}{\text{pCi}/\ell}$ x 0.8 pCi/ℓ) as compared with the measured concentration of 0.003 WL in Building 8.

Results of Water Sample Analyses

The concentrations of uranium, radium, and thorium in a sample of process water taken from the Niagara River near Hooker (water sample no. 1, Fig. 1) are given in Table 9. Also listed are the results for a tap-water sample taken from the Niagara Falls city water system (sample no. 2), and the maximum permissible concentration for water[6] (MPC_w) for each isotope measured. The concentrations of radionuclides measured in sample 1 were not significantly different from those measured in sample 2. Furthermore, the concentration of each radionuclide measured in each sample was at least an order of magnitude below the MPC_w. Concentrations of ^{238}U contained in sludge samples taken from man-holes 301 and 306 (Fig. 2) were 6.2 and 0.9 pCi/g, respectively.

Summary

Concentrations of ^{238}U and ^{226}Ra in soil samples from the site were not significantly different from concentrations of those nuclides in background samples taken off-site. Levels of fixed and transferable alpha and beta-gamma contamination throughout the site, including the site of former Building 5, were within NRC[2] and proposed ANSI[3] guidelines for the release of property for unrestricted use. External gamma radiation levels in most parts of the site were within the range

situations. ERDA has adopted these guidelines as the basis for remedial action criteria[8] developed for structures constructed on or with uranium mill tailings in Grand Junction, Colorado. According to these criteria, structures other than dwellings or school classrooms may be considered for remedial action if the indoor radon daughter concentration level is 0.03 WL or greater. In the absence of data on indoor concentrations of radon daughters, remedial action may also be considered if the external gamma radiation level is 0.15 mR/hr or more. It was seen in Table 4 that the maximum exposure rate to gamma-rays was 0.028 mR/hr (integrated dose equivalent of approximately 55 mrem/yr for 40 hours per week). Radon daughter concentrations in the air in Buildings 6, 7, 8, and 9 were well below the above-mentioned guideline level of 0.03 WL. Radon and radon daughter concentrations measured over a short period may not reflect accurate average annual conditions. However, the low concentrations of radium found in the soil at Hooker, together with the low radon and radon daughter concentrations in the buildings, suggest that there is no potential radon daughter inhalation hazard in the buildings. In a water sample taken from the Niagara River at a point where process water from Hooker flows into the river, concentrations of uranium, radium, and thorium were more than an order of magnitude below the MPC_w. Concentrations of ^{238}U in two sludge samples taken from man-holes on the site were 6.2 pCi/g and 0.9 pCi/g, respectively and represent from $\sim$ 1 to 2.5 times normal background concentrations of uranium.

to Release for Unrestricted Use or Termination of Licenses for Byproduct Source, or Special Nuclear Material, USNRC (December 1975).

3. Proposed American National Standard, ANSI N328-197, "Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use" (1976).

4. M. Eisenbud, Environmental Radioactivity (McGraw-Hill, 1963) pp. 158-159.

5. A. Toth, "Determining the Respiratory Dosage from RaA, RaB, and RaC Inhaled by the Population in Hungary," Health Phys. 23, 281-199 (1972).

6. Code of Federal Regulations, Title 10, Part 20, "Standards for Protection Against Radiation," Appendix B.

7. Department of Health, Education, and Welfare, "Recommendations of Action for Radiation Exposure Levels in Dwellings Constructed on or With Uranium Mill Tailings," Letter from P. Peterson, acting Surgeon General, to R. L. Cleere, Executive Director, Colorado State Department of Health, July 27, 1970.

8. Code of Federal Regulations, Title 10, Part 712, "Grand Junction Remedial Action Criteria," Federal Register, Vol 41-No. 252, December 30, 1976.

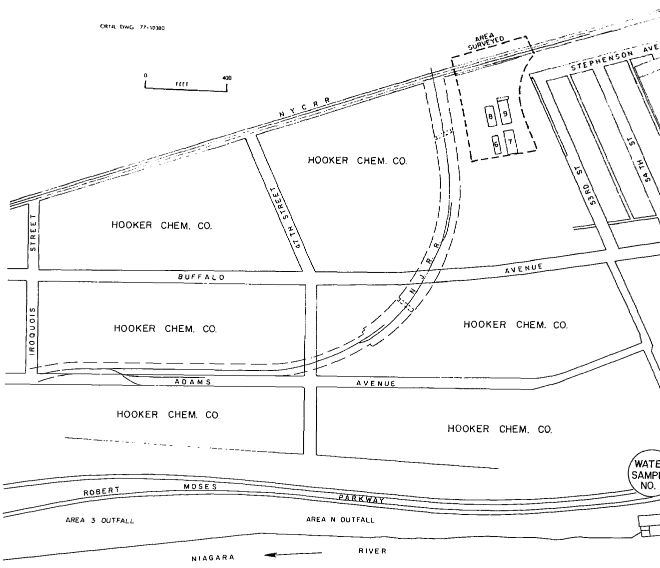


Fig. 1. Map of Hooker Chemical Company.

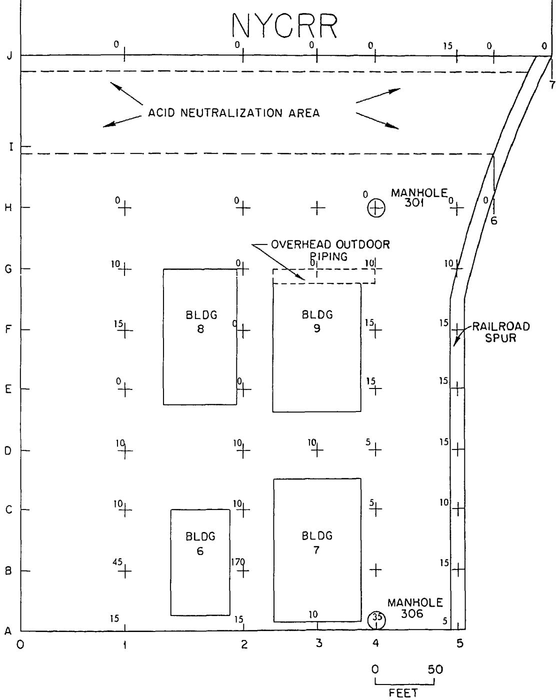


Fig. 2. Alpha Contamination Measured on Outdoor Surfaces. (Readings expressed in dpm/100 cm^2.)

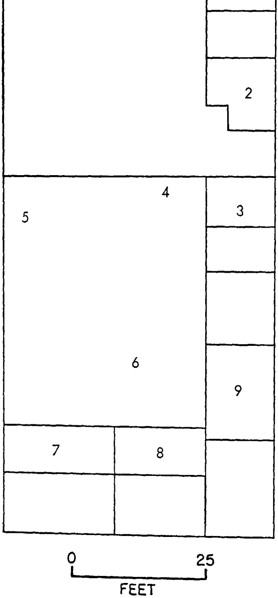
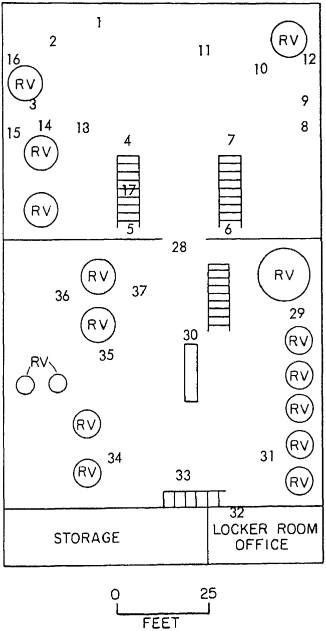


Fig. 3. Plan View of Building 6, and Location of Survey Points Listed in Table 1.



RV = reaction vessel

Fig. 4. Plan View of Lower Level of Building 7, and Location of Survey Points Listed in Table 2 (see also Fig. 5).

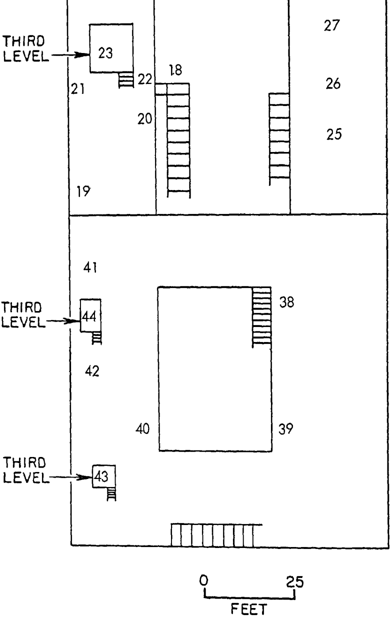


Fig. 5. Plan View of Upper Level of Building 7, and Location of Survey Points Listed in Table 2 (see also Fig. 4).

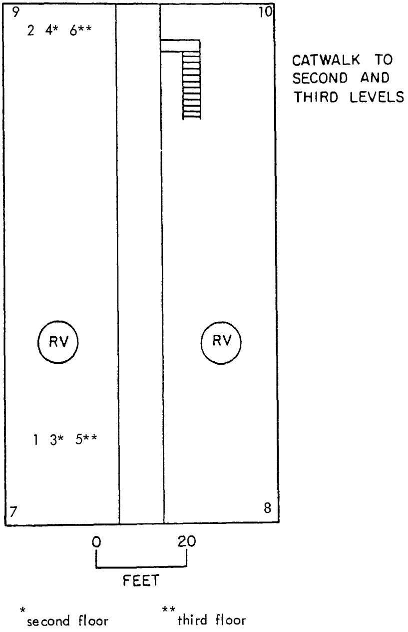


Fig. 6. Plan View of Building 8 and Location of Survey Points Listed in Table 3.

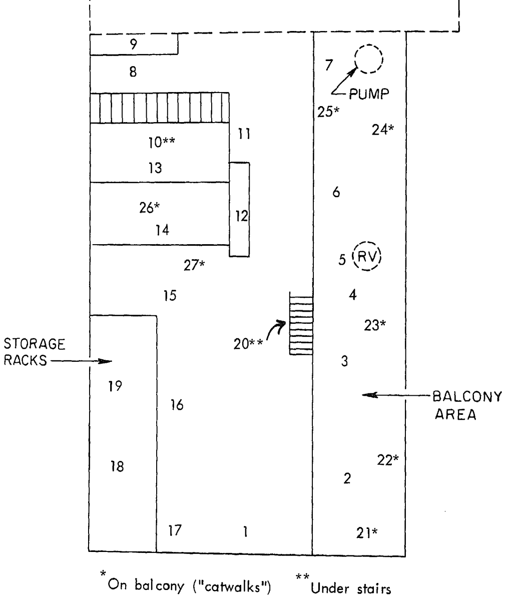


Fig. 7. Plan View of Building 9, and Location of Survey Points Listed in Table 4.

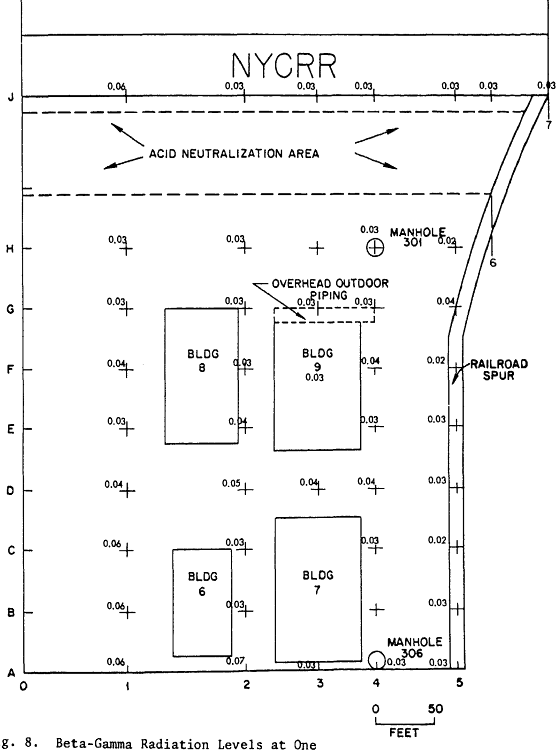


Fig. 8. Beta-Gamma Radiation Levels at One Centimeter Above the Outdoor Surfaces. (Expressed in mrad/h.)

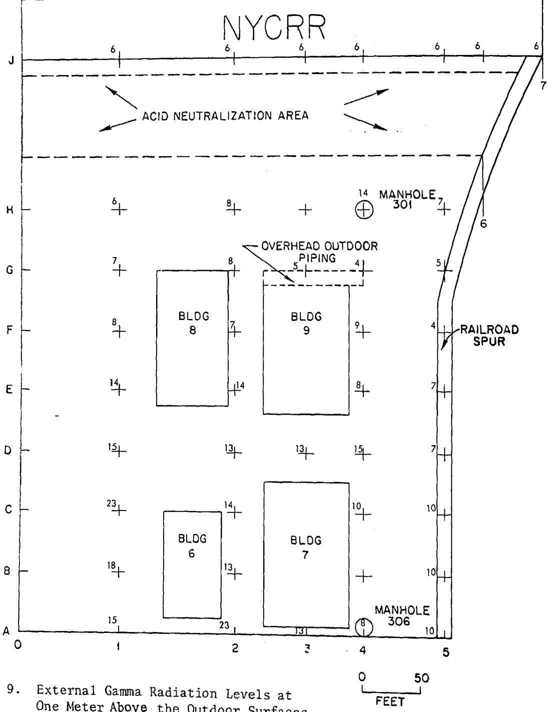


Fig. 9. External Gamma Radiation Levels at One Meter Above the Outdoor Surfaces. (Expressed in μR/hr.)

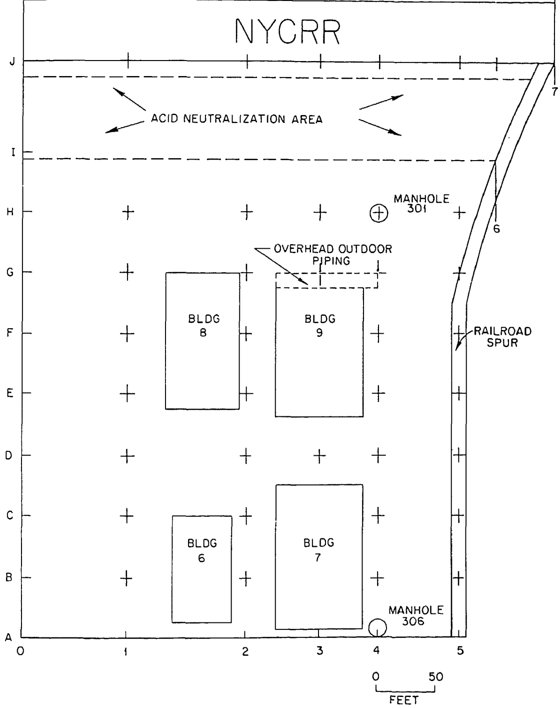


Fig. 10. Sampling Grid Used to Locate Soil Samples (Soil sampie results given in Table 6).

1	15	0.05	11
2	10	0.04	10
3	10	0.04	10
4	15	0.02	10
5	10	0.03	10
6	10	0.04	10
7	15	0.03	15
8	5	0.03	16
9	10	0.03	11

1	0	0.03	11
2	25	0.03	12
3	10	0.03	10
4	10	0.02	10
5	5	0.03	11
6	5	0.02	11
7	15	0.03	11
8	25	0.03	10
9	30	0.05	12
10	25	0.05	14
11	10	0.03	10
12	0	0.05	10
13	45	0.06	11
14	15	0.03	14
15	0	0.03	14
16	10	0.05	14
17	5	0.03	11
18	0	0.03	10
19	5	0.05	11
20	25	0.03	11
21	25	0.03	11
22	5	0.04	11
23	5	0.05	11
24	10	0.02	10
25	25	0.02	9
26	10	0.05	10
27	5	0.03	9
28	10	0.02	9
29	0	0.05	11
30	10	0.04	8
31	10	0.04	8
32	15	0.06	14
33	10	0.04	8
34	15	0.05	11
35	10	0.04	11
36	10	0.04	11
37	15	0.04	8
38	10	0.03	7

40	10	0.03	7
41	0	0.04	7
42	10	0.04	7
43	5	0.04	8
44	10	0.02	6

1	5	0.03	16
2	0	0.03	19
3	5	0.04	14
4	0	0.03	13
5	10	0.03	12
6	0	0.02	8
7	10	0.04	9
8	0	0.03	20
9	0	0.03	14
10	5	0.03	15

1	5	0.03	11
2	5	0.03	8
3	15	0.03	8
4	10	0.03	8
5	15	0.04	9
6	10	0.04	11
7	10	0.03	11
8	25	0.06	23
9	15	0.03	23
10	10	0.03	28
11	15	0.03	10
12	5	0.02	14
13	0	0.04	14
14	25	0.03	11
15	10	0.05	12
16	25	0.06	11
17	5	0.05	11
18	10	0.01	8
19	15	0.06	9
20	5	0.04	10
21	10	0.04	10
22	5	0.03	8
23	15	0.02	8
24	10	0.03	7
25	5	0.03	7
26	0	0.02	8
27	5	0.04	8

6	1	120
6	3	190
7[b]	22	200
7	42	140
9[c]	4	120
9	7	140
9	12	140

[a]See Fig. 3.

[b]See Figs. 4 and 5.

[c]See Fig. 7.

A3	Surface	0.4	0.5
B1	Surface	0.7	0.6
C1	Surface	0.7	0.6
D1	Surface	0.7	0.8
E1	Surface	1.8	1.5
F5	0'-1'	0.6	0.6
G1	Surface	0.5	0.8
G2	Surface	0.7	2.0
H1	Surface	1.7	1.6
H4	Surface	0.7	0.7
J1	Surface	0.4	0.4
J6	0'-1'	0.9	1.1
J7	0'-1'	1.9	1.7
K1	Surface	0.9	1.6
K2	Surface	1.4	1.4
K3	Surface	1.4	1.4
K4	Surface	1.5	2.1
K5	Surface	1.5	1.5
K6	Surface	1.4	1.3
K7	Surface	1.4	1.3
OSB-1	Surface	1.7	1.7
OSB-2	Surface	1.0	0.9

[a] Sample identification refers to grid location, except for samples OSB-1 and OSB-2, which are background samples taken off the site.

8	25 ft from main entrance	0.8
9	Center of building	0.3

[a]The minimum detectable radcn concentration under the survey conditions is ∿0.1 pCi/liter.

8	25' from entrance	0.003
9	25' from entrance	<0.001

[a] A working level (WL) is defined as any combination of radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy.

Table 9. Results of water sample analyses (concentrations given in pCi/

Sample	^{228}Th	^{230}Th	^{224}Ra	^{226}Ra	^{234}U
1	5.5×10^{-4}	1.3×10^{-4}	$<1.1 \times 10^{-3}$	$<1.1 \times 10^{-3}$	2.7 x 1
2	5.9×10^{-4}	2×10^{-4}	$<1.4 \times 10^{-3}$	$<1.4 \times 10^{-3}$	2.3 x 1
CG_W (soluble)	7	2	2	3×10^{-2}	30

and the other uses a gas-flow proportional counter to detect the alpha radiation.

The alpha scintillation survey meter consists of a large area ($100\ cm^2$) ZnS detector with a photomultiplier tube in the probe which is coupled to a portable scaler/ratemeter (see Fig. I-A). The ZnS detector is covered with a 5-mil aluminized mylar sheet in order to make the instrument light-tight. The mylar, in turn, is covered with a grid to prevent puncturing the detector when surveying over rough surfaces. This instrument is capable of measuring alpha surface contamination levels of a few dpm/100 cm^2 but must be used in the scaler mode for this purpose. It is highly selective for densely ionizing radiation such as alpha particles; the instrument is relatively insensitive to beta and gamma radiation.

The gas-flow proportional counter uses propane gas as the detection medium. Through front panel meter readings it can be used to measure alpha contamination levels from a few hundred dpm/100 cm^2 to several hundred thousand dpm/100 cm^2. If individual pulses are counted, this instrument can also be used for measurements down to a few dpm/100 cm^2. The probe has a surface area of approximately 61 cm^2 and has a 2.5-mil aluminized mylar covering with a protective grid. Due to the protective grid, the active area of the probe is 50 cm^2. It is relatively insensitive to other than alpha radiation. This instrument, shown in Fig. I-B, is manufactured by the Eberline Instrument Company as their model PAC-4G meter with a probe.

A portable Geiger-Muller (G-M) survey meter is the primary instrument for measuring beta-gamma radioactivity. The G-M tube is a halogen-quenched stainless steel tube having a 30 mg/cm^2 wall thickness and presenting a cross-sectional area of approximately 10 cm^2. Since the G-M tube is sensitive to both beta and gamma radiation, measurements are taken in both an open window and a closed-window configuration. Beta radiation cannot penetrate the closed window, and, thus, the beta reading can be determined by taking the difference between the open and closed window readings. This meter is shown in Fig. I-C.

The G-M survey meter was calibrated at ORNL for gamma radiation using an NBS standard Ra source. The gamma calibration factor is typically of the order of 2600 cpm/mR/hr.

In order to assess beta-gamma surface dose rates from uranium contaminated surfaces using this instrument, a field calibration was performed. The G-M survey meter was compared with a Victoreen Model 440 ionization chamber (see Fig. I-D) and was found to produce 1750 cpm/mrad/hr with a 25% standard deviation for a wide variety of surfaces, including concrete, wood, pavement, bricks, and steel beams.

Gamma Scintillation Survey Meter

A portable survey meter using a NaI scintillation probe is used to measure low-level gamma radiation exposure. The scintillation probe is

of 300 cpm/μR/hr.

SMEAR COUNTERS

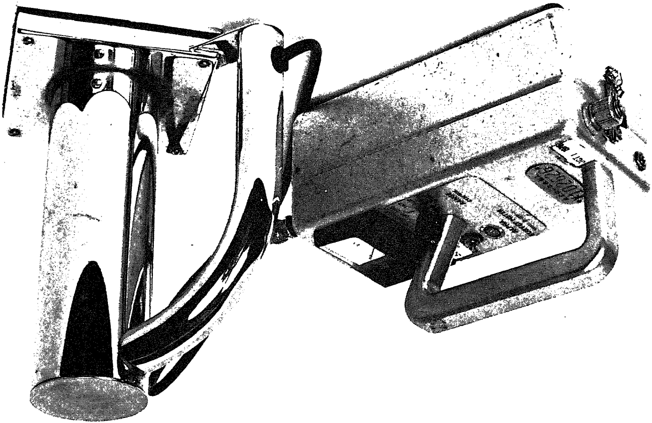
Alpha Smear Counter

This detector assembly, used for the assay of alpha emitters on smear paper samples, consists of a light-tight sample holder, a zinc sulfide phosphor and a photomultiplier tube. This detector assembly was used with electronic components housed in a portable NIM bin (see Fig. I-F). The electronics package consisted of a preamplifier, a ORTEC 456 high voltage power supply, a Tennelec TC 211 linear amplifier and a Tennelec TC 545 counter-timer.

The alpha smear counter was used in the field and was calibrated daily using an alpha source with a known disintegration rate.

Beta Smear Counter

The beta smear counter consisted of a thin mica window ($\sim$ 2 mg/cm^2) G-M tube mounted on a sample holder and housed in a 23-cm diam x 35-cm high lead shield. Located under the counter window is a slotted sample holder, accessible through a hinged door on the shield. An absorber can be interposed in the slot between the sample and the counter window to determine relative beta and gamma contributions to the observed sample counting rate. The electronics for this counter were housed in a portable NIM bin and consisted of a Tennelec TC 148 preamplifier, an ORTEC 456 high voltage power supply and a Tennelec TC 545 counter-timer.



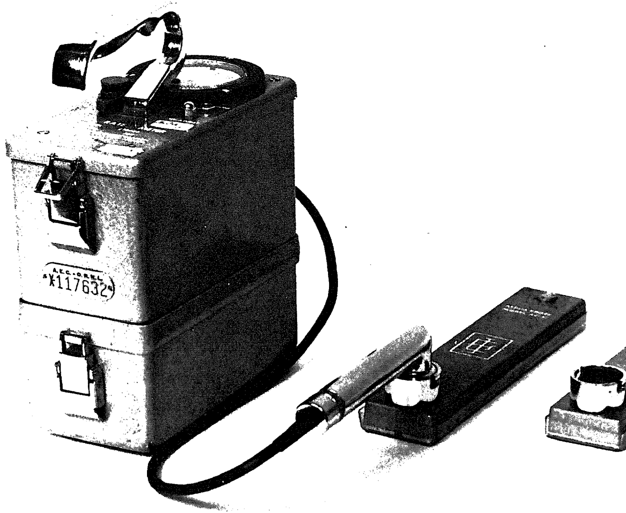


Fig. I-B. Gas-flow Proportional Alpha Survey Meter.

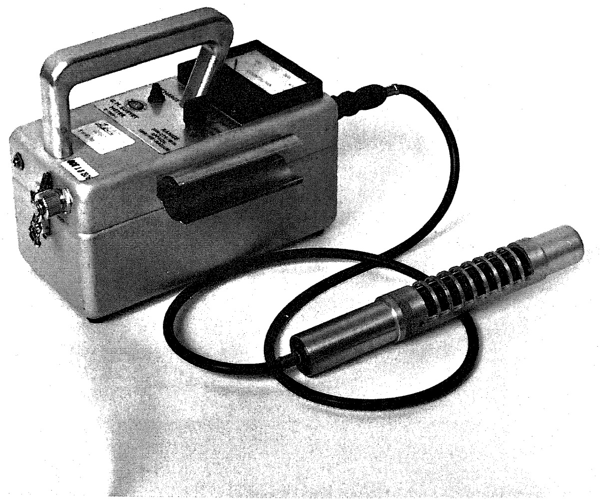


Fig. I-C. Geiger-Muller Survey Meter.

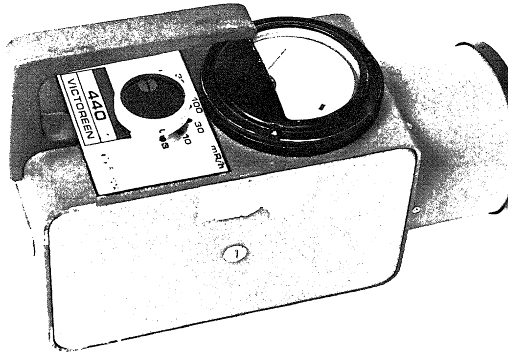


Fig. I-D. Victoreen Model 440 Ionization Chamber.

Fig. I-E. Victoreen Model Thyac III Ratemeter.

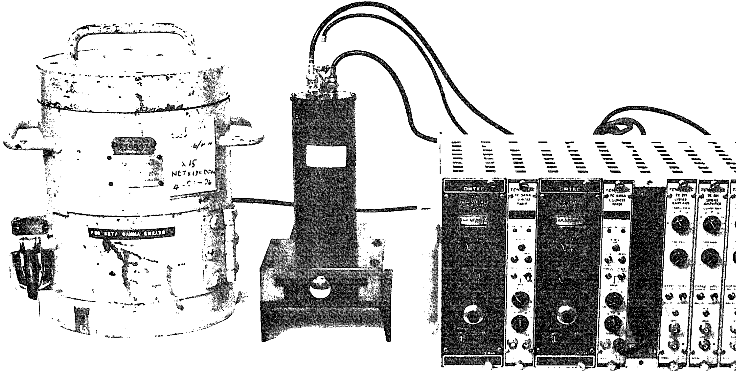


Fig. I-F. Alpha and Beta Smear Counters.

Fig. I-6 Mobile Lab Used on Survey

alpha activity, the concentrations in air of Po, Bi and Pb may be calculated.

Particulate ^{222}Rn daughters attached to airborne dust are collected on a membrane filter with a pore size of 0.4 microns. A sampling time of 5 minutes and a flow rate of 12 LPM are used. This filter sample is then placed under a silicon surface barrier detector and counted. The detector and counting system used for radon daughter measurements are shown in Fig. II-A. Usually, counting of this kind is performed with a vacuum between the sample and the detector which requires a complicated sample holder and time-consuming sample changing methods. Experiments at this laboratory have shown that ease in sample handling is obtained with little loss in resolution when helium is used as a chamber fill gas.(3) In this counter, helium is flowed between the diode and the filter sample, which are separated by a distance of 0.5 cm. One integral count of the ^{218}Po alpha activity is obtained from 2 to 12 minutes, and two integral counts of the ^{214}Po activity are obtained from 2 to 12 minutes and 15 to 30 minutes, respectively. All counting intervals are referenced to t = 0 at the end of sampling.

The equations describing the ^{222}Rn progeny atoms collection rates on the filter are of the form

$$\frac{dn_i(t)}{dt} = C_i v + \lambda_{i-1}\, n_{i-1}(t) - \lambda_i n_i(t) \qquad (1)$$

where

The solution of Eq. (1) is of the form

$$y = e^{-ax} [y_0 = \int F(x) e^{ax} dx]$$

From the general form of the solution, specific equations can be obtained describing the number of each ^{222}Rn decay product collected on the filter as a function of time. Also by letting v = 0 in Eq. (1), a set of equations describing the decay on the filter of each ^{222}Rn progeny can be obtained. The equations describing the decay of ^{222}Rn progeny on the filter can be integrated and related to the integral counts obtained experimentally. Values for the total activities of ^{218}Po, ^{214}Pb, and ^{214}Bi on the filter at the end of sampling are obtained by applying matrix techniques. The airborne concentrations are obtained by solving the equations describing the atom collection rates on the filter. A computer program has been written to perform these matrix operations, to calculate the air concentrations of the radon progeny, and to estimate the accuracy of the calculated concentrations.

Technique for the Measurement of Radon Concentrations in the Air

A Lucas Chamber (Fig. II-B) consists of a 95-ml glass flask, coated inside with a uniform layer of zinc sulfide. For measurements of radon concentration in the air, the flask is evacuated to a pressure of 50 microns. The flask is then taken to a location where a sample is desired and the collection valve is opened. After collection of air in the flask,

version factor is 2.02 pCi/1 per cpm. After the sample has been counted, the flask is again evacuated to 50 microns to prevent contamination.

II-3. P. T. Perdue, W. H. Shinpaugh, J. H. Thorngate and J. A. Auxier, "A Convenient Counter for Measuring Alpha Activity of Smear and Air Samples," Health Phys. 26, 114 (1974).

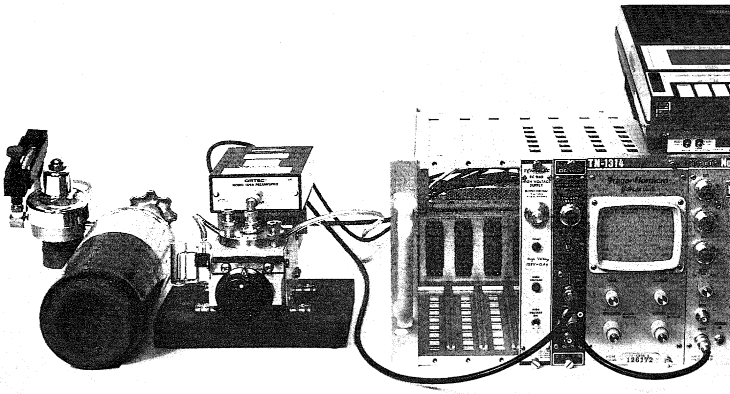


Fig. II-A. System Used for Measurement of Radon Daughter Concentrations

Fig. II-B. Lucas Chamber.

counting of radioactivity in environmental samples (see Figs. III-A, III-B). During counting of the samples, the holder is used to position ten of the sample bottles around the cylindrical surface of the detector, parallel to and symmetric about its axis, and two additional bottles across the end surface of the detector, perpendicular to and symmetric with its axis. With a 300 cc sample and a graded shield developed for use with the system, it is possible to measure 1 pCi/g of ^{232}Th or ^{226}Ra with an error of ± 10% or less.

Pulses are sorted by a 4096-channel analyzer (see Fig. III-C), stored on magnetic tape, and subsequently entered into a computer program which uses an iterative least squares method to identify radionuclides corresponding to those gamma-ray lines found in the sample. The program relies on a library of radioisotopes which contains approximately 700 isotopes and 2500 gamma-rays and which runs continuously on the IBM-360 system at ORNL. In identifying and quantifying ^{226}Ra, six principal gamma-ray lines are analyzed. Most of these are from ^{214}Bi and correspond to 295, 352, 609, 1120, 1765, and 2204 KeV. An estimate of the concentration of ^{238}U is obtained from an analysis of the 93 KeV line from its daughter ^{234}Th.

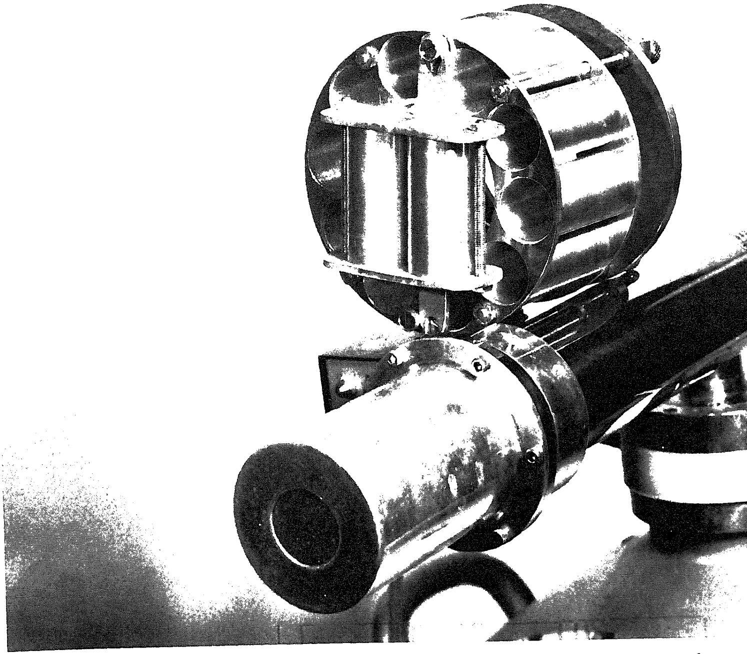


Fig. III-A. Holder for GeLi Detector System Samples.

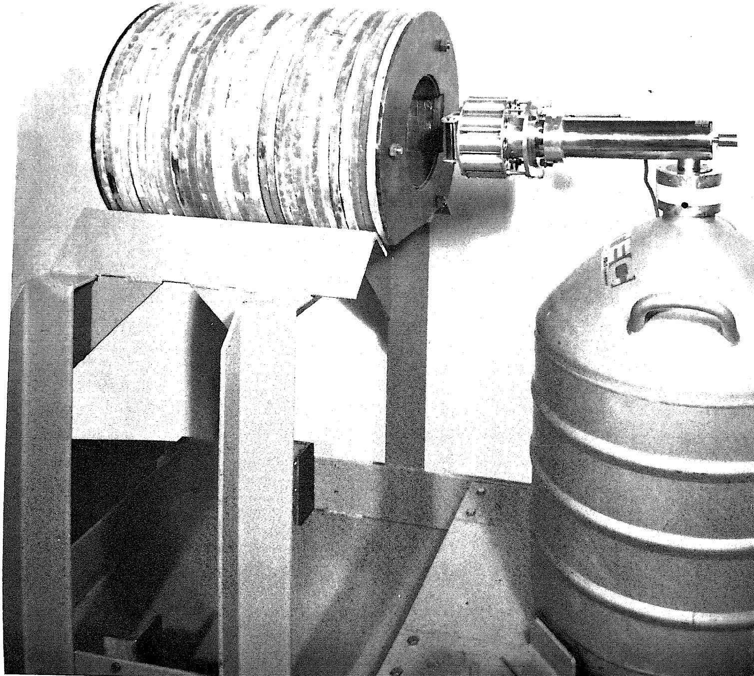


Fig. III-B. Geli Detector System.

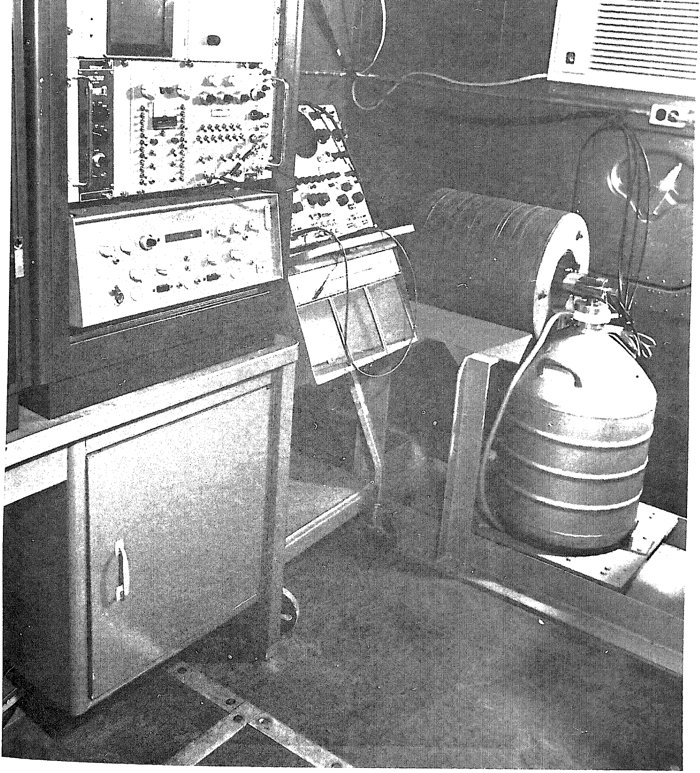


Fig. III-C. 4096 - Channel Analyzer.